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ABSTRACT

To test the usefulness of single subject statistical designs for biofeedback, three experiments were conducted comparing biofeedback to meditation, and to a compound stimulus recognition task. In a statistical sense, this experimental design is best described as one experiment with two replications. The apparatus for each of the three experiments was the same: stimulus presentation and process control, data collection and storage, and data reduction and statistical analysis. The procedure for the three experiments was identical, except for counter balancing the order of treatments. Each of the three college subjects was given six weeks of meditation training, three weeks of biofeedback training, and one session of training with the compound stimulus (visual, auditory and tactile). Twenty seconds of electroencephalogram data were sampled from each of the three treatments. Analysis of variance confirms the hypothesis that biofeedback is significantly different from the other treatments and that the interaction between biofeedback and stimuli is also significant. The paper states that, in particular, the statistical difference between biofeedback and the other two treatments of this experiment is strong evidence to refute claims that biofeedback does not do anything. It is felt that the single subject approach described in this paper is very useful for biofeedback studies. Numerous tables and graphs are included. (PN)

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The Reliability of Single Subject Statistics for Biofeedback Studies

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The Reliability of Single Subject Statistics

for Biofeedback Studies

Bremner, Yost, and McKenzie (1982) demonstrated that single subject experimental designs can be applied to studies in which human EEG measures are the dependent variable and that this can be done with statistical reliability. This same technique was later used by Brown (1983) who showed that not only did the EEG's of individual cats reflect experimentor manipulations of the treatment variable but that the reliability of results when compared across 6 single subjects experiments was extremely high. In addition, McKendree (1982) successfully applied this single subject experimental design and statistical analysis to human EKG data and demonstrated that the single subject technique was applicable to electrophysiological data other than EEG. Therefore, it seems apparent to the authors of the present paper that the single subject design technique and statistical analysis referred to above was the obvious technique for biofeedback data.

The value of single subject design for biofeedback research and clinical applications is that in most cases the individual subject is the experimental unit. In short,

the group mean of 20 subjects undergoing EEG biofeedback training is rather meaningless because knowing the group mean of 20 subjects (or the variance, for that matter) would provide little information for determining whether a treatment worked for a particular subject or patient. Not only is this true, but the highly ideographic nature of human EEG's together and calculating an average is about as meaningful as having the police add the fingerprints of 20 criminals together in order to find the average criminal. What is needed in the clinic, and therefore should be tested in the laboratory, is to determine which biofeedback treatment works for each patient and not the average effect of biofeedback on all of the patients.

In order to test the usefulness of single subject statistical designs for biofeedback, three experiments were conducted comparing biofeedback to meditation, and to a compound stimulus recognition task. In a statistical sense, this experimental design is best described as one experiment with two replications. The specific hypotheses were that the EEG for the biofeedback treatment would be significantly different from that of the other two treatments and that the treatment by side interaction (laterality effect) also would be significant. Furthermore, the hypothesis was that these significant effects would be reliable across the three experiments (subjects).

In a study of this type, it is important to make certain features of the statistical technique apparent at the outset. Shine, in a series of papers (1975, 1982a, 1982b), tested the use of an analysis of variance and a multivariate analysis of variance with single subject designs to see if the assumptions of these statistics were violated. He concluded that most of the assumptions on which these statistical techniques are based were so robust that single subject analysis was valid. The most critical assumption, however, was independence of the subject variable. This assumption can be most easily understood by visualizing a treatment by subjects design in which 20 subjects undergo each of 2 treatments (experimental and control). If the subjects are chosen in some correlated (non-random) manner, the error terms are invalid and, therefore, the F-test is invalid. In a single subject design, measures on the same subject replace the typical between-subjects variable discussed above. It is difficult to believe that measures on the same subject will not be correlated, particularly when EEG is the measure. However, it is easy to test the samples of EEG to determine that the consecutive samples (seconds) of EEG taken from the same electrode are not correlated. Therefore, it is appropriate to use analysis of variance or multivariate analysis of variance on EEG data.

Methods

Subjects - The subject in experiment one was a 20 year-old co-ed who had more than one year experience in meditation but no previous experience in biofeedback. The subject in experiment two was a 21 year-old male college student who had some previous training in meditation but not in biofeedback. The subject in the third experiment was a 20 year-old male college student who had had no previous meditation training.

Apparatus - The apparatus for all three experiments was the same. They can be labeled as stimulus presentation and process control, data collection and storage, and data reduction and statistical analysis. The stimulation and process control functions were built around a TI 960 process control computer. This computer controlled the biofeedback circuit and various stimulus presentations. The biofeedback circuit has been published previously (Helmer, 1975). The stimulus presentations were most directly under the control of a micro processor (Apple II computer) which in turn was controlled by the TI 960. The Apple II computer controlled the onset and duration of three sensory stimuli as follows: 1000 Hz tone, a target on a television monitor and a tactile vibrator.

The EEG data collection and storage were done using standard methodology. Pin electrodes served as transducers

over the right and left occipital cortex (01 and 02) referenced to the ipselateral ear. These EEG leads were each connected to a Data Incorporated (2124) amplifier which was connected to a strip chart recorder and a Vetter 700 series analog tape recorder.

The data reduction and statistical analysis functions were performed by three computers networked together. The process of converting the analog EEG signal to numbers (A to D conversion) was performed by a Digital Equipment Corporation PDP 11/24 which sent the digital data online to an IBM 3031 computer. The IBM 3031 used a Fast Fourier Analysis (FFT) program to analyze the digitized EEG data (Eddy and Bremner, 1983; Yost, Cooper, and Bremner, 1983). The IBM 3031 was also used to obtain a set of descriptive statistics on the output of the FFT. Finally, a selected portion of the output of the FFT was sent online to an IBM PC-XT which was used to do the inferential statistical analysis and graphing of results.

Procedure - The procedure for the three experiments (subjects) was identical, except for counter balancing the order of treatments. The subject was given six weeks of meditation training, three weeks of biofeedback training, and one session of training with the compound stimulus. The meditation training consisted of using a modified Silva Mind Control technique (McKnight, 1972). The subject sat quietly with eyes open and visualized a favorite place of

rest. The biofeedback training was similar to that used by Bremner and Moritz (1972). Familiarization with biofeedback was taught to the subject by personal, individual instruction during which the subject listened to filtered right occipital lead EEG from an auditory speaker. The filter was set for the subject's eyes closed dominant alpha frequency. The instructions were to keep the "alpha sound" present while keeping both eyes open. The intention was to make the subject as sophisticated as possible about meditation and biofeedback and the stimulus task.

The three stimuli making up the compound stimulus were a visual stimulus, an auditory stimulus and a tactile stimulus. The visual stimulus was a Lorraine Cross on the television monitor, the auditory stimulus was a 1000 Hz tone over the earphones and the tactile stimulus was a vibrator modified from an electric toothbrush and strap over the subject's ankle. The intent was to bombard the sensory system and the reticular formation with an abundance of information. In addition, the subject was given a task to maintain his vigilance. The instructions were to press a button immediately following the termination of the compound stimulus. The compound stimulus was of different durations. The data reported here were recorded after many practice trials with this stimulus.

During the session from which the data were sampled,

the subject did the three treatments (biofeedback, meditation and compound stimuli) described above with a full complement of leads, vibrator, and earphones attached. It is important to note that the subject had considerable training with these tasks and was familiar with the instrumentation.

The procedures for all three experiments were identical with the exception that one subject used Transcendental meditation rather than the Silva Method. In addition, the second and third experiments had the treatments presented in a different order.

Data Management Procedure - Twenty seconds of EEG data were sampled from each of the three treatments discussed for each of the two occipital electrodes. Thus, there were 40 seconds of EEG for each treatment (20/electrode), and since there were three treatments, there was a grand total of 120 seconds of EEG data for these experiments (subjects). These 120 seconds of EEG were A to D converted and Fast Fourier Analyzed (FFT) by the computers described in the Apparatus section. The FFT produced a power spectrum for each second (i.e., 20 spectra per electrode per condition or 120 spectra for the experiment). A power spectrum is a squared voltage value (Power) for each frequency requested in the analysis. In this case, 4 Hz to 25 Hz were requested of the analysis program.

A set of descriptive statistics was applied to 40 spectra of the meditation treatment. These descriptive statistics were visually reviewed to pick a two Hz band for further analysis. Prior to the experiment, we arbitrarily determined to look only at the alpha band frequencies (8-13 Hz). The two Hz window chosen within the alpha band for experiment one was from 8.75 Hz to 10.25 Hz. In effect, we chose one score (power within a narrow frequency band) for each second of EEG sampled. These scores became the measures for what was a treatment by subjects analysis of variance. However, the typical subject's variable was replaced by seconds of EEG data. The experimental design is shown in Figure 1.

* *

Insert Figure 1 about here

* *

Statistical Procedure - The statistical procedures consisted of testing the 120 EEG scores as shown in Figure 1. The between variable is seconds with two within variables electrodes (left and right occipital), and treatments (biofeedback, meditation, and compound stimuli). In addition, an analysis was done to determine if the scores representing the seconds of EEG were correlated. Finally, after all three experiments were analyzed, Fisher's (1950) technique

for determining the exact probability of Independent Probabilities was used to determine if the results of all three experiments taken as a group could have occurred by chance.

Results

Table 1 contains the results of the analysis of variance as applied to the EEG data of the first experiment. It is apparent from the table that the main effect for treatment (T4) is significant ($p < .001$) and the treatment by sides interaction (T2) is significant ($p < .001$). This confirms the hypothesis that the biofeedback treatment is significantly different from the other two treatments.

* *

Insert Table 1 about here

* *

The results of experiment 2 are shown in Table 2. It is apparent from the table that there is a significant main effect for treatments (T4 $p < .001$) and that the interaction (T2 $p < .001$) is significant.

* *

Insert Table 2 about here

* *

The results for experiment 3 are given in Table 3. Again, both the main effect for treatments (T4 $p < .001$) and interaction (T2 $p < .02$) are significant.

* *

Insert Table 3 about here

* *

After the three experiments were completed, Fisher's method of combining independent probabilities was used to combine the probabilities applied to the results of all of the three experiments. The results of Fisher's method for combining the three probabilities was .0001. In order to verify the independence of seconds of EEG spectral data, a correlational analysis with lags of one through five was applied to the EEG data of each subject. The results of this analysis showed that there were no significant correlations ($p < .3$) among seconds of EEG data, thus justifying the use of analysis of variance with single subject EEG data as dependent the measure.

The interaction of treatment by laterality (side of the head for all 3 subjects) is shown in Figure 2. All three graphs are typical of the types of interactions found in the study.

* *

Insert Figure 2 about here

* *

Discussion

A review of the ANOVA tables and figures in the Results section confirms the hypothesis stated in the introduction that biofeedback is significantly different from the other two treatments and that the interaction between sides and treatments (biofeedback and stimuli) is also significant. The interaction between sides, the meditation treatment and the biofeedback treatment, was not significant. The authors are quite willing to believe that the right and left occipital cortex does similar things during meditation and biofeedback but rather different things when the sensory system is bombarded by stimuli as it is during the compound stimulus task.

However, the thrust of this paper is not neurophysiology but statistical technique, and the results have convinced us that the single subject approach described above is very useful for biofeedback studies. In particular, the statistical difference between biofeedback and the other two treatments is strong evidence to refute those who claim that biofeedback does not do anything (Andreychuk and Skriver, 1982). It is apparent from the histograms for the three experiments that presenting a person with biofeedback stimuli is quite different from bombarding the subject with complex sensory stimuli. This gives the researcher or clinician something on which to base decisions besides the verbal report of the

person or the technician's visual inspection of the EEG data. Thus, statements like "it looks like we are getting some change," are replaced by "there is a significant difference between the biofeedback data and the data recorded during the control condition" (i.e., the compound stimuli). Therefore, the treatment is effective.

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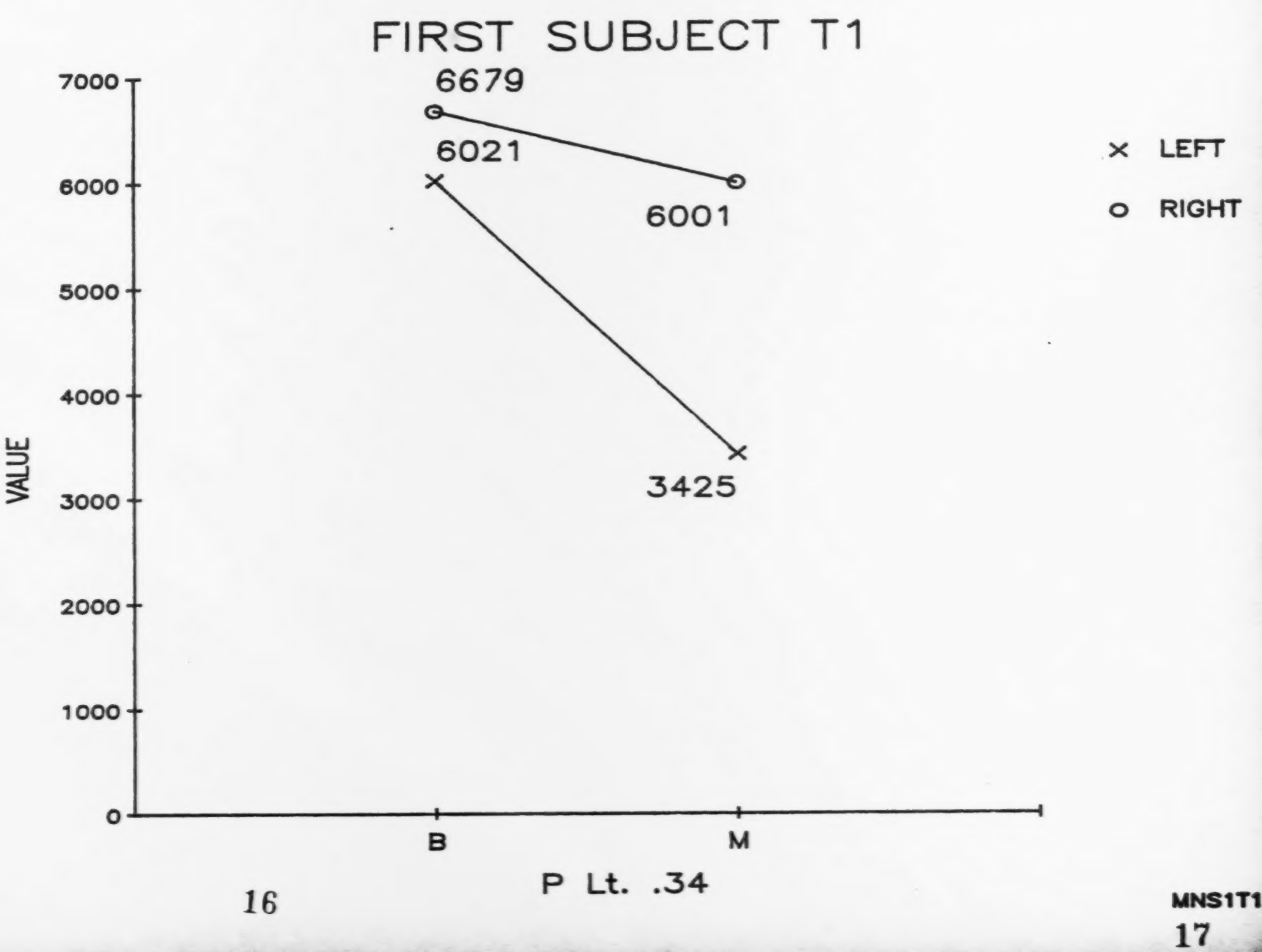
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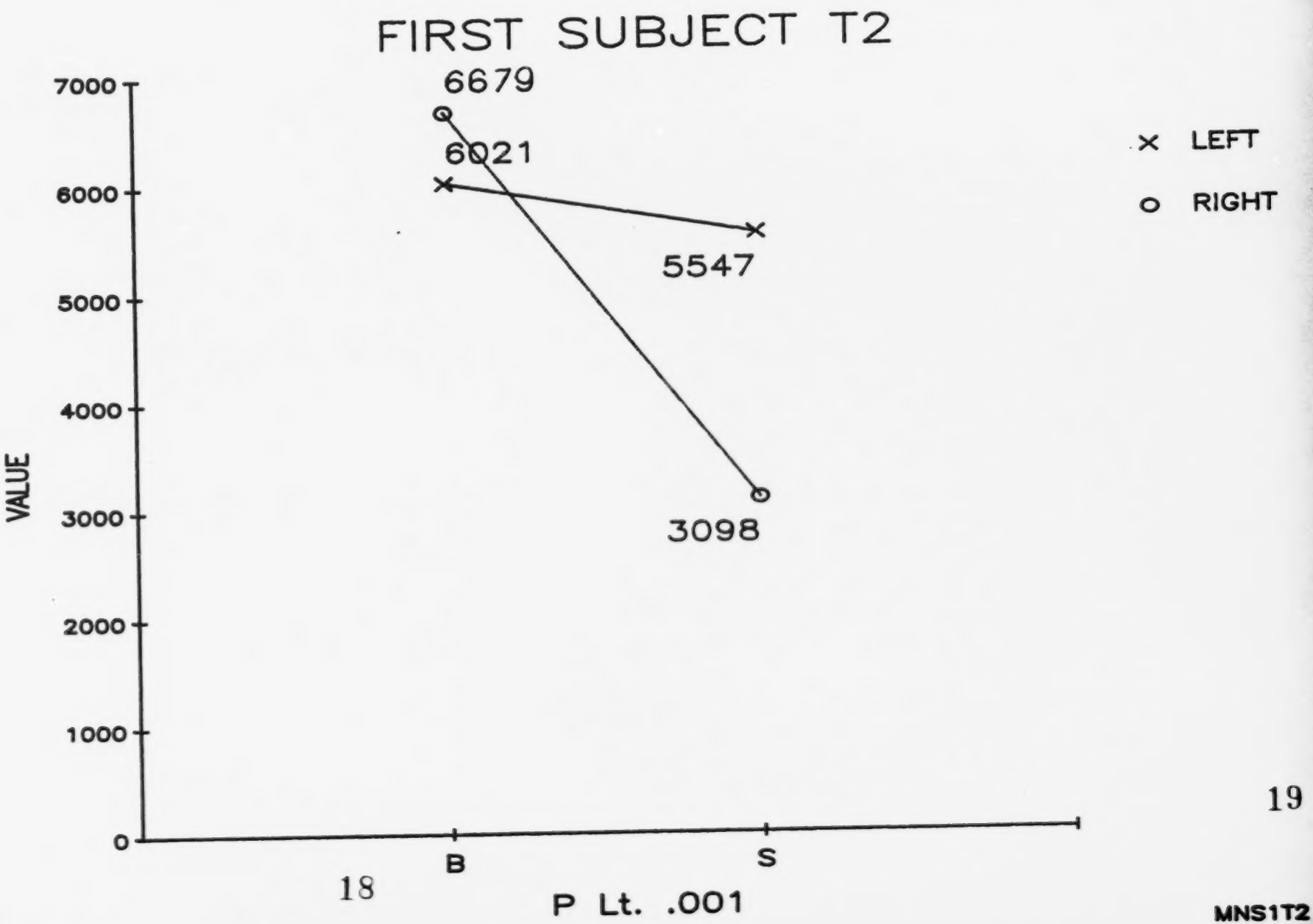
MNS1T1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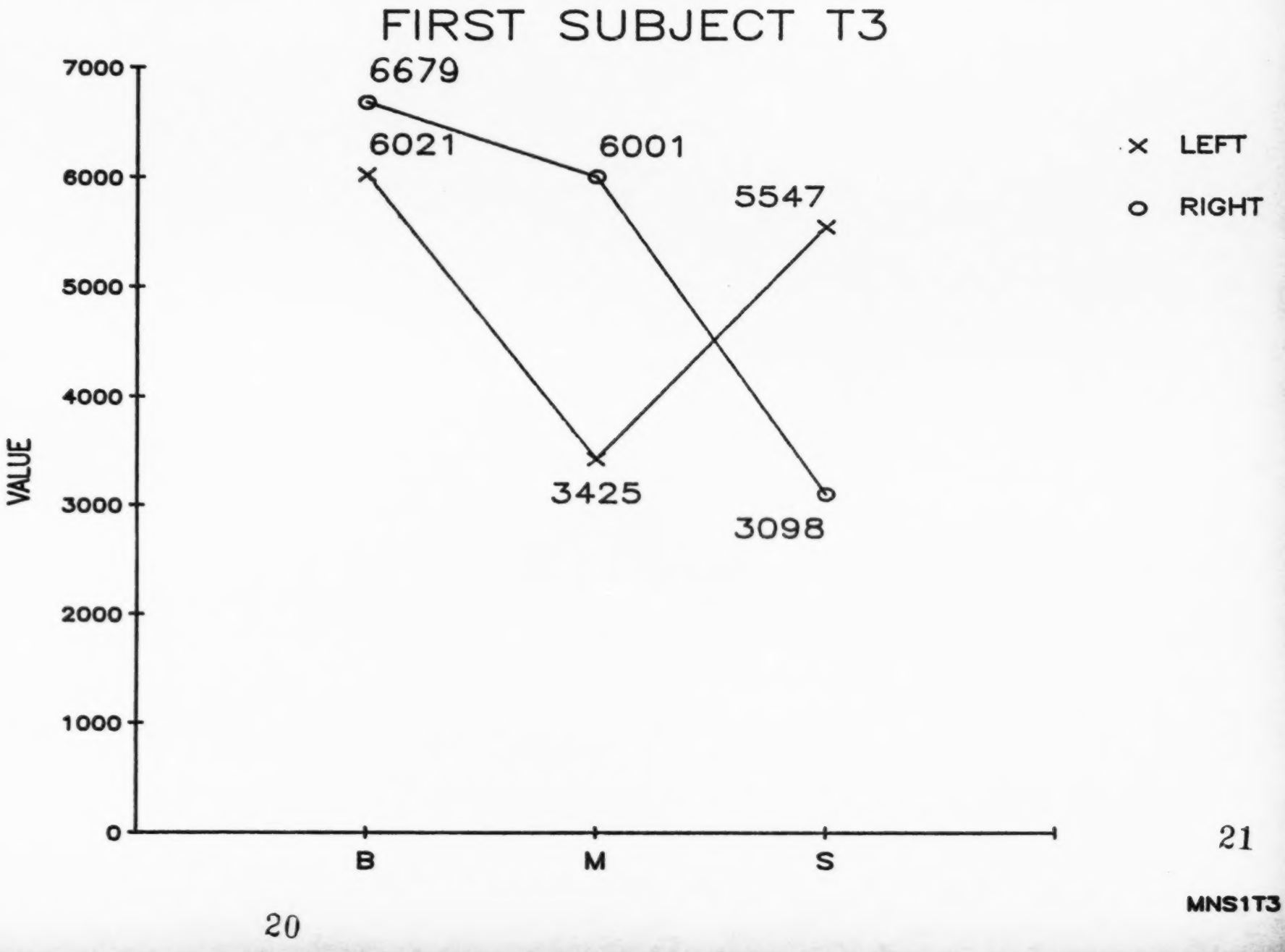
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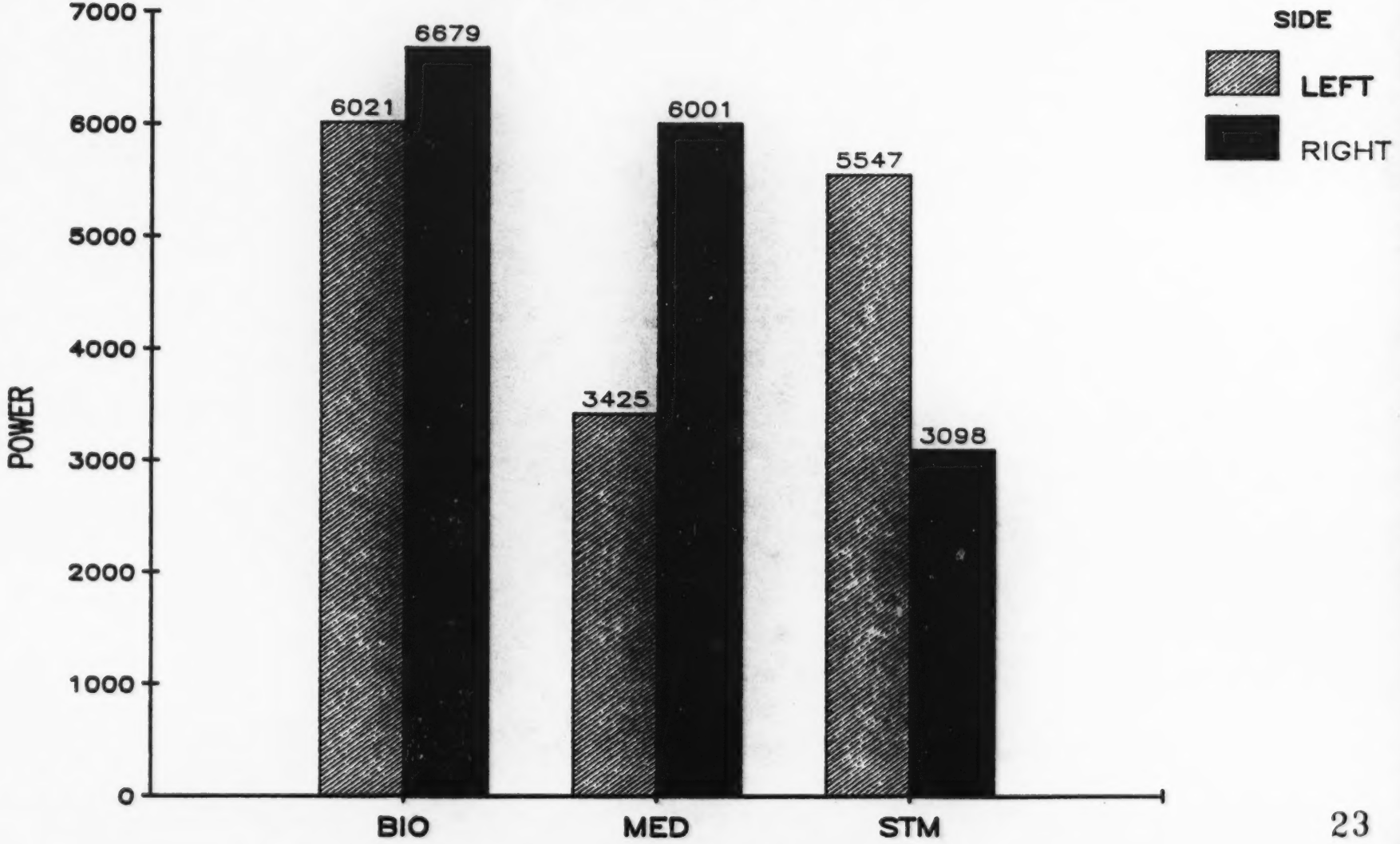
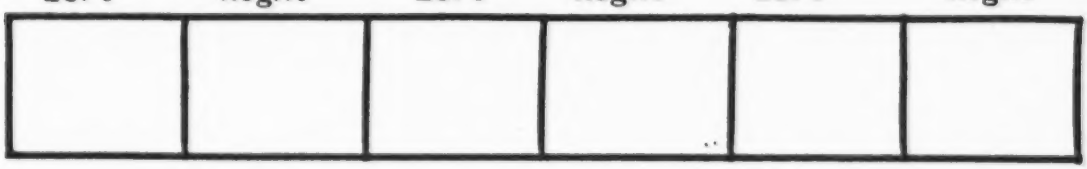


T4 P. Lt. .001
T5 P. Lt. .640

MNFSTSUB

Figure 1

Experimental Design and Contrast Matrix



Weighting Factor	1	1	1	1	1	1
Statistical Tests	Contrasts					
T_1	-1	1	1	-1	0	0
T_2	1	-1	0	0	-1	1
T_3	1	-1	-2	2	1	-1
T_4	2	2	-1	-1	-1	-1
T_5	1	-1	1	-1	1	-1

Table 1

Analysis of Variance for the First Subject

	Biofeedback		Meditation		Multi Stimuli	
	Left	Right	Left	Right	Left	Right
Mean	6021	6679	3425	6001	5547	3098
Std.Dev.	6967	11706	4631	5447	3076	2480

Test	F (1,112)	Probability
T_1	.90	.34
T_2	20.0	.001
T_4	51.4	.001
T_5	.21	.64

Table 2

Analysis of Variance for the Second Subject

	Biofeedback		Meditation		Multi Stimuli	
	Left	Right	Left	Right	Left	Right
Mean	7676	14312	15991	23572	5080	5092
Std.Dev.	9341	13398	15383	15570	5100	4489

Test	F (1,113)	Probability
T_1	1.29	.25
T_2	36.18	.001
T_4	124.5	.001
T_5	2.17	.14

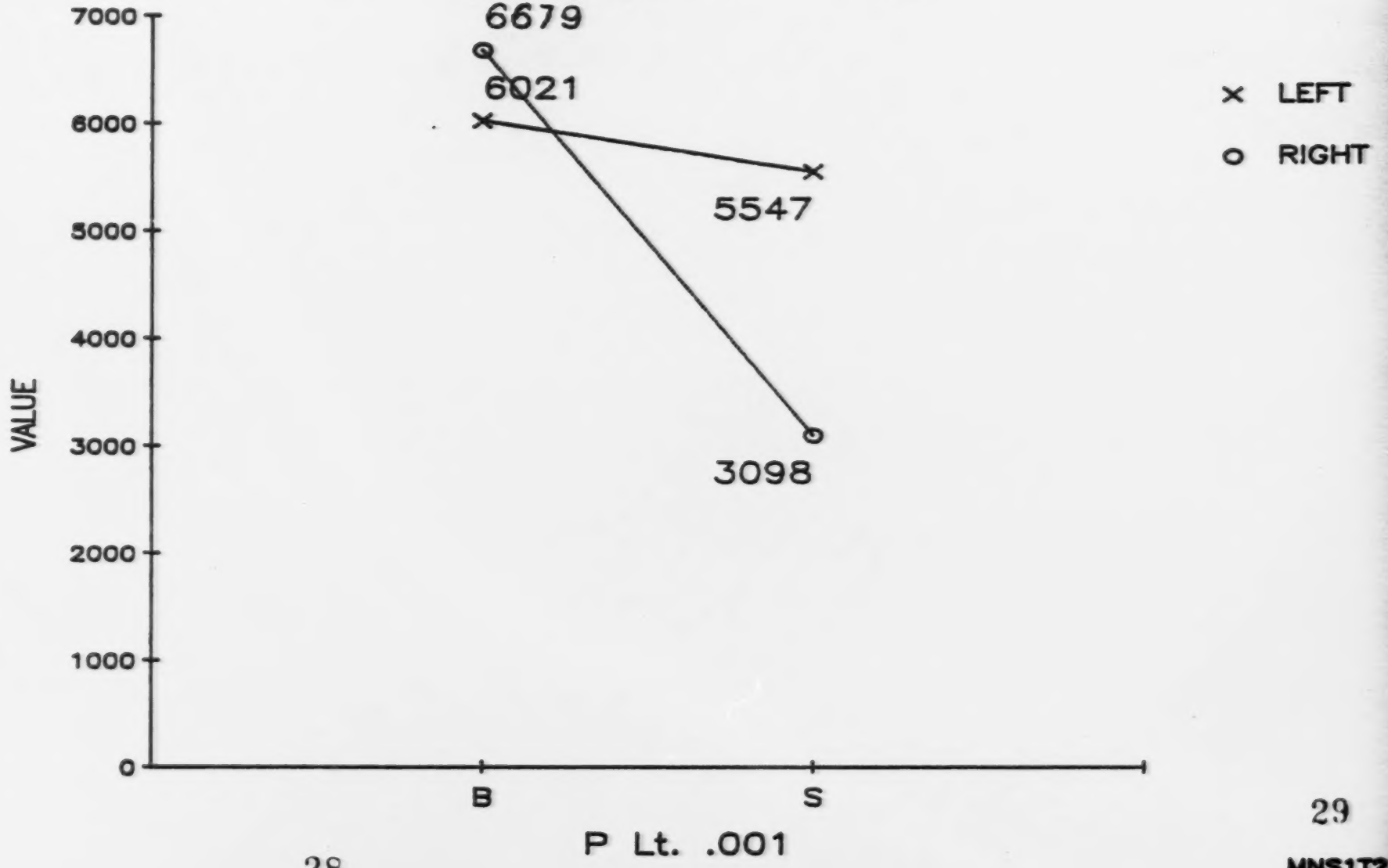
Table 3

Analysis of Variance for the Third Subject

	Biofeedback		Meditation		Multi Stimuli	
	Left	Right	Left	Right	Left	Right
Mean	33151	34926	10068	14954	3168	1418
Std.Dev.	27786	27664	12819	14161	3708	1001

Test	F (1,114)	Probability
T_1	.38	.53
T_2	5.8	.02
T_4	116.6	.001
T_5	8.44	.004

FIGURE 2
SUBJECT1 — T2



MNS1T2

FIGURE 2A
SUBJECT2 — T2

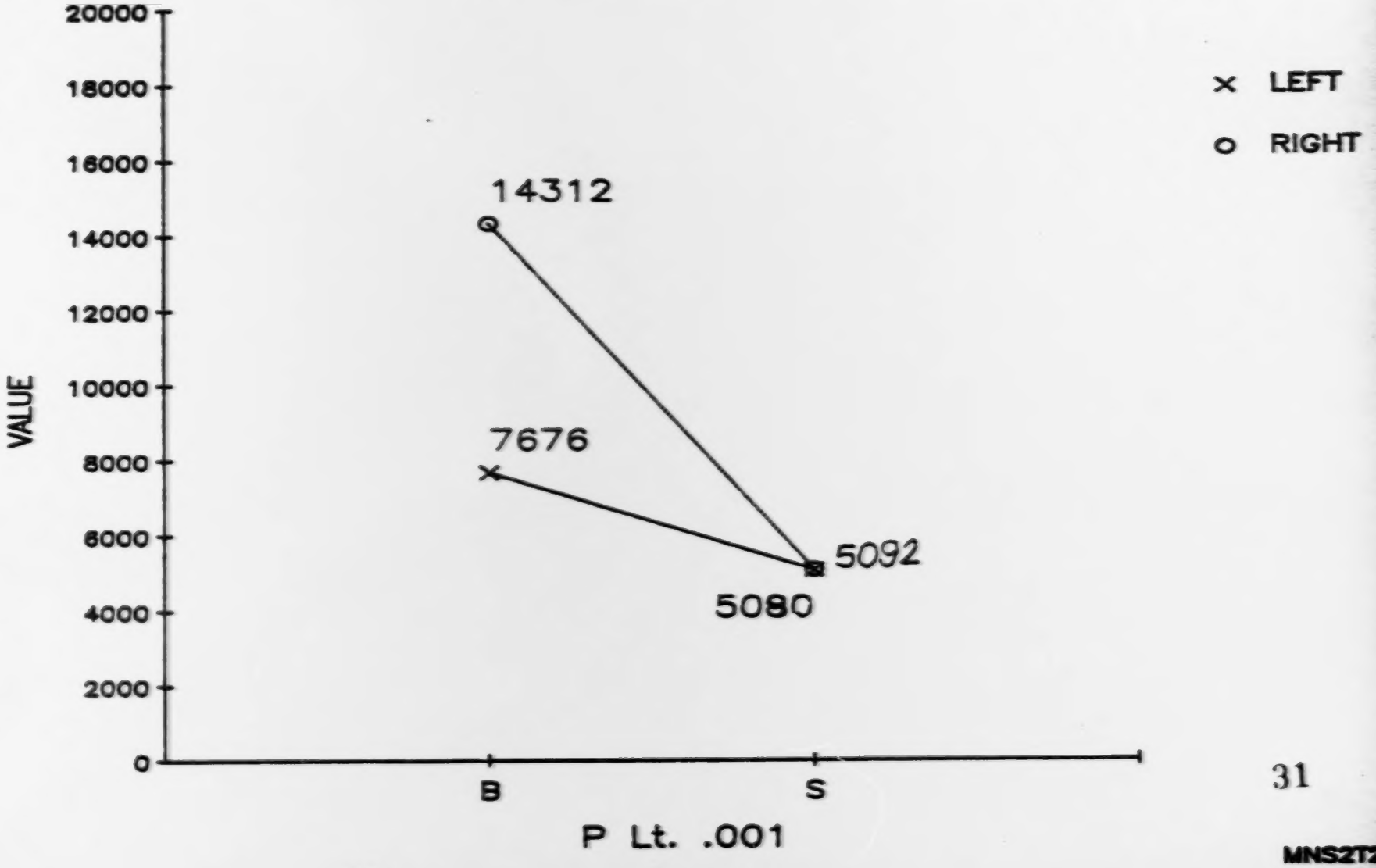
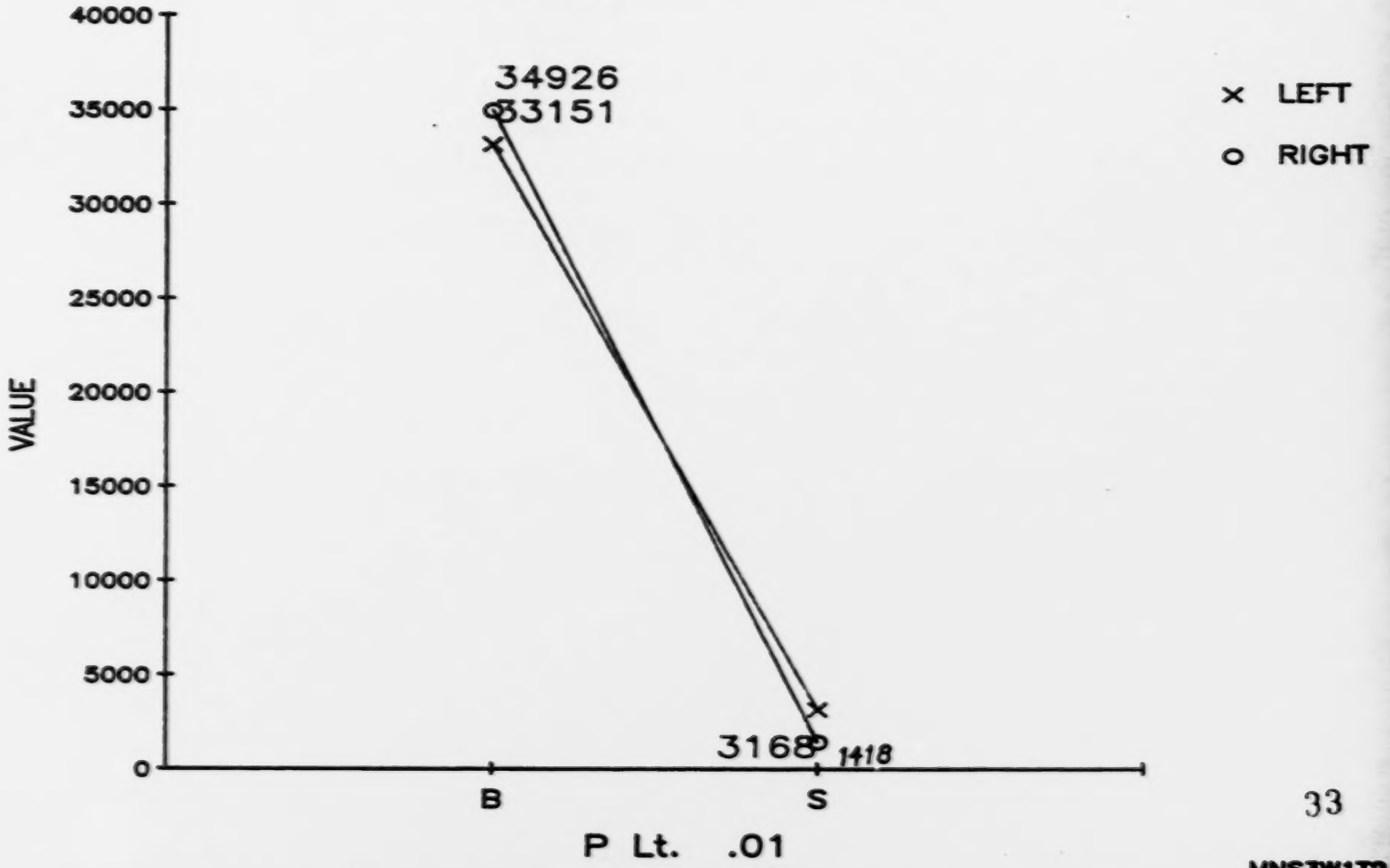


FIGURE 2B
SUBJECT3 — T2



P Lt. .01

MNS3W1T2